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Long term in situ measurements of hygrothermal conditions at critical points in four cases of internally insulated historic solid masonry walls

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ABSTRACT

In heritage buildings with solid masonry walls, where external insulation is not an option, insulating internally is an alternative way to improve indoor climate and reduce energy consumption and heat loss through external walls. This study presents results from hygrothermal measurements performed in four different buildings in Denmark where internal insulation has been installed. The buildings are all heritage buildings from 1877–1932 and of solid masonry walls. The insulated façades differ in orientation, surface treatments, location, and insulation system. The insulation materials used are phenolic foam and polyurethane (PUR) foam, with calcium silicate channels in a grid of 40 × 40 mm. Measurement results and hygrothermal assessments indicate that a vapour barrier does not contribute positively to the performance of the system and the more vapour open, the better performance on solid masonry. However, the performance is highly dependent on other parameters like insulation thickness and surface treatment, and above all: the external hygrothermal loads. Therefore, before the application of internal insulation, every case should be carefully assessed in order to find the most suitable solution with regards to both thermal and hygrothermal performance.

1. Introduction

As society's urge for reduction of energy consumption is on the rise, so is the need for energy retrofitting measures to be implemented in the existing building stock. The European building stock itself accounts for 40% of European energy consumption [1]. Also, more than 40% of European residential buildings were built prior to 1960 [2], thus being prior to any attention being given to energy consumption, including heat loss through external walls in cold and temperate climates. Thermal insulation is a natural measure in order to reduce the heat loss through the building envelope. Thermal insulation does not only reduce the energy demand for heating, but also provides a better indoor environment in regards to thermal comfort, utilization of indoor space, and indoor air quality [3]. External insulation is usually the moisture safest and most efficient method for reduction of heat transfer through the external walls, as it provides the existing construction with protection from the external environment and eliminates thermal bridges [4–9]. This is however not possible in many historic buildings, as the façades are either preservation worthy, or of too much cultural and aesthetic value, to change the exterior aesthetics. Therefore, internal insulation is introduced in these cases. Internal insulation however introduces several risks to the existing construction, as the hygrothermal conditions in the original construction are changed. As a result, the risk of interstitial condensation is increased [10–12], and the drying potential inward is reduced as the permeability is reduced by the insulation [11,13,14]. The increased risks of high moisture in the wall, inevitably leads to an increased risk of mould growth [15], and decay of the existing wood embedded in the structure. Furthermore, as a result of reduced temperature and drying potential of the existing wall, the risk of frost damage to the surface is also increased [9,10,15,14]. Internal insulation should thus not be installed without considerations to the building physics aspects. It might not be possible to achieve the desired *U*-value, or the desired heat loss reductions, but given the risks involved, it is far more feasible in the long run, to implement a moisture safe solution.

There are several types of insulation marketed for internal insulation [11], including capillary active and hydrophilic insulation materials [8,10,16,17], and traditional hydrophobic insulation materials including a vapour barrier. Internal insulation systems on the market can be separated into three groups based on their basic properties; 1) capillary active and vapour open, 2) vapour open

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and 3) vapour tight systems. Capillary active systems have the advantage of a high moisture buffering capacity, yielding the possibility of redistributing absorbed moisture for evaporation [18]. The capillary active systems are also vapour open. Vapour open systems allow transport of water vapour in the construction, but the risk of interstitial condensation increases as moist indoor air reaches the cold external wall. A vapour open system can be combined with a smart vapour retarder, whose vapour resistance varies depending on the relative humidity [19]. A high vapour resistance in cool periods would prevent interstitial condensation, and a reduced vapour diffusion resistance can allow drying of the wall. Vapour tight systems completely inhibit moisture transfer through the insulation, preventing vapour from diffusing through the insulation and condensing on the external wall. All these systems naturally have pitfalls; the capillary active system will lose its ability for moisture redistribution if there is not full contact between the materials in the system. Also, no organic material should exist at the cold surface of the insulation [20] and for systems with vapour barriers, proper installation and complete tightness is needed. Furthermore, these systems leave the wall extra sensitive to external moisture loads, as inward drying is limited.

There has been increasing focus on internal insulation in heritage buildings for the past few years; a limited number of studies with long-term in situ measurements are available. Orlik-Kożdoń et al. [11] found no critical moisture conditions in two cases of internal insulation of expanded polystyrene and lightweight aerated concrete on a solid brick wall. However, measurements were performed for only 6 months, and furthermore, there was an external curtain wall, protecting the construction from external moisture loads etc. Klõšeiko et al. [13,21] on the other hand, obtained high relative humidities in four cases of internal insulation on a brick wall during a 9 month study. The four materials tested in this case include; calcium silicate 50 mm, aerated concrete (AAC) 60 mm, polyurethane foam (PUR) with capillary active calcium silicate channels in a grid of 40 × 40 mm (IQ-Therm) 50 mm and polyisocyanurate foam (PIR) 30 mm. Calcium silicate proved the best performance in regard to moisture performance, however calcium silicate also has the highest thermal conductivity. Harrestrup et al. [22] monitored a case of internal insulation of 40 mm aerowolle on a heritage brick building, and the effect of intentional thermal bridges above and below supportive wooden beams. They found that leaving a 200 mm uninsulated gap above and below the beams yielded a lower risk of mould growth, however this was found to be very dependent on the orientation and the thickness of the existing wall. Toman et al. [8] ran a long-term study of 4 years, on a 19th century building, with solid brick walls, external render and paint, insulated with a hydrophilic mineral wool insulation board, and no vapour barrier, however, a vapour retarder was placed on the interior surface of the existing wall. The study showed excellent hygrothermal conditions and no risk of interstitial condensation at any point in time during the 4 year period. In a recent study by Hamid et al. [23], a similar study was performed with in situ measurements in solid masonry with internal insulation, and validated simulation models. The study emphasized the importance of the orientation due to the significant influence of wind driven rain, and solar driven vapour. Furthermore, the study emphasized the significant risk of mould growth at the wall-insulation interface, and the cold side of an integrated vapour barrier given the presence of biological material.

This study aims to add to the knowledge of internal insulation systems by investigating the success or failure of two different insulation systems and thicknesses on four different case buildings with long-term monitoring in real climate conditions. Initially the measurements were initiated in order to gain empirical data for research of internal insulation of historical brick buildings with regard to moisture performance of the wall and beam ends. Based on the measured data, and hygrothermal simulations performed in Delphin 5.8 [24], it is sought to gain an understanding of how internal insulation can safely be applied.

2. Method

The presented study is built around long-term monitoring of hygrothermal performance of historic building façades retrofitted with internal insulation. Monitoring results are assessed with mathematical risk models and with 1D hygrothermal numerical simulations. In the case of Meinungsgade, the 1D simulation has also been verified by 2D simulations.

2.1. Insulation systems

Two different insulation systems with different insulation thicknesses are studied. In total, four cases are presented. Both insulation materials in this study are highly insulating rigid foams, however they are initially not vapour permeable or capillary active potentially trapping possible moisture accumulation. One of the systems included in this study, system 2, has been provided with channels of calcium silicate with the purpose of enabling capillary transport of possible condensate, as well as leaving the system vapour permeable. The complete insulation systems in this study are set up as fully adhered to the existing wall and the systems are described in Table 1;

The two systems have thermal conductivities of 0.02 W/mK and 0.037 W/mK for system 1 and system 2 respectively. In all cases, the insulation is applied to a 1½-brick (360 mm) thick solid masonry wall with internal rendering. The *U*-values are estimated based on an assumed identical brick type and the theoretical *U*-value reductions in each are displayed in Table 2 together with an overview of the presented cases. Each case is elaborated in Sections 2.2.1–2.2.4.

2.2. In situ measurements and case buildings

In all cases, temperature and relative humidity sensors of the type Rotronic HygroClip2 (accuracy ± 0.8% RH, ±1 K, up to 90% RH) have been installed at the interfaces between the original wall, and the insulation, as well as at the end of the beams. The case of Thomas Laubs Gade however, only has sensors at the wall-insulation interface. These are considered the areas of interest, as this is where potential risks concerning damaging moisture can arise. At the interfaces, there is an increased risk of interstitial condensation, which produces e.g. the risk of mould growth. The same goes for the beam ends with an increased risk of wood rot, as the drying potential and temperature are reduced when internal insulation is applied, and thus increasing the relative humidity. The sensors at the interfaces are placed in either existing joints, or purposely designed notches in the existing wall. Sensors behind beam ends are placed through holes drilled in the beam, and the holes then sealed with foam. Examples of sensor locations can be seen in Fig. 1.

The sensors are set to log every 1 minute; and hourly averages have been generated and will be presented in the results section. The data was acquired by an online system provided by the company Electromec Engineering Service. The test buildings presented in this paper, are all multistory residential brick buildings from 1877–1932, built in a traditional Danish building style, with wooden beams and wooden lath to support intermediate floors. The four cases are located in Denmark; three of them in Copenhagen, and one in Haderslev.

2.2.1. Ny Allegade 10, Haderslev

The case building in Haderslev is a 2 story building from 1932, with a bare brick surface, as seen in Fig. 2. In the spring of 2015,